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LABORATORY STUDY OF THE RESPONSE OF ROUND WHITEFISH LARVAE TO A BENTHIC SLED SAMPLER

Report No 88-334-K

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ABSTRACT

Laboratory studies were conducted with a 1/3 scale benthic sled to determine factors affecting capture success of round whitefish larvae. Capture efficiency declined significantly with increasing substrate irregularity (cobble size). Larvae made few movements to avoid capture as the sled approached, but their habit of remaining very close to the substrate made them very difficult to capture on coarse cobble substrates. Average capture rates increased about 45% during tests in "twilight" conditions, as larvae tended to rise several centimeters off bottom in very dim light, suggesting that field sampling should be done at night. Sled towing speed (0.5 to 1.0 m/s) did not clearly affect results, but the sled's tendency to bounce over rough substrates at higher speeds suggests that towing speeds should be kept as low as possible. Tests were made with a deflector plate mounted ahead of the sled to create current vortices and raise larvae off the bottom as the sled nets approached. However, low catches suggest that as tested, the deflector was not beneficial. Tests conducted with a stationary net oriented into the currents created by a pump or by draining the tank suggest that round whitefish larvae may be susceptible to capture by drift nets oriented into longshore currents.

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EXECUTIVE SUMMARY

**LABORATORY STUDY OF THE RESPONSE OF
ROUND WHITEFISH LARVAE
TO A BENTHIC SLED SAMPLER**

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Chemical Research Department

Ongoing studies to assess possible thermal effects on spawning round whitefish at Pickering, Darlington and the Bruce Nuclear Power Development have utilized a benthic sled to sample round whitefish larvae. Due to the small and irregular catches of the larvae in the field, a study of larval response to the sled sampler was conducted in the laboratory, with a view to improvement of field apparatus and sampling procedures.

A 1/3 scale model of the benthic sled was used for laboratory studies. Tests were conducted in a long flume (15 m x 1.2 m) filled to a depth of about 0.8 m. For each test, 400 newly hatched larvae were placed in a central section of the flume, contained by fine mesh screens. This area was covered by a cobble substrate, either fine (2-5 cm) or coarse (5-15 cm) material. At the start of a test, the screens were raised, and the sled was towed the length of the flume, passing over the larvae. Larvae captured by the sled were enumerated, and the flume was then flushed and dewatered to remove all remaining larvae prior to the start of the next test. A video system with a low-light camera was used to monitor larval response during each test. Tests were conducted in daylight (10 lux) and twilight (approximately 10^{-3} lux). Tests were also conducted at towing velocities from 0.5 m/s to 1.0 m/s. In some tests, a deflector plate was mounted in front of the sled in order to create current vortices and raise larvae off the bottom, making them more vulnerable to capture.

Video observations made during both daylight and twilight tests indicated that most larvae were within 10 cm of the substrate, and should be vulnerable to capture. Therefore, sled capture efficiency was computed on the basis of the relative widths of the flume and sled nets. Capture efficiency was significantly affected by substrate composition. Preliminary daylight tests with a smooth (concrete) flume bottom suggested a capture efficiency near 75%. On fine cobble, daylight efficiency declined to 12.2%, and with the addition of coarse cobble, efficiency was depressed to 5%. Larvae made few movements to avoid capture as the sled approached, but their habit of remaining very close to the substrate made them very difficult to capture on coarse

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cobble substrates. Also, the irregular surface caused the sled to bounce several centimeters off bottom, further reducing it's effectiveness.

Attempts were made to improve catch efficiency through addition of a deflector plate mounted ahead of the sled and through increased towing velocity. At a towing speed of 0.5 m/s, capture efficiency with the deflector plate was only 5.3%, compared with 12.2% obtained without the deflector. At a towing speed of 1.0 m/s, the capture efficiency was 6.6% with the deflector and 5.6% without the deflector. Thus, addition of the deflector was of little value at higher speeds and may have been detrimental at lower speeds. However, it should be noted that these differences were not statistically significant. Increased towing speed resulted in a lower average catch without the deflector. While these results were not statistically significant, the sled's tendency to bounce over rough substrates at higher speeds suggests that field towing speeds should be kept as low as possible.

Tests were conducted in daylight and twilight with both fine and coarse cobble substrates. On fine cobble, average daylight catch efficiency was 12.2%, while it was 18.4% in twilight. On coarse cobble substrates, efficiencies were 5.0 and 6.6% respectively for daylight and twilight tests. Although these differences were not statistically significant (only 3 replicate tests were run), the average twilight catch was about 45% higher than the average daylight catch. As the larvae were seen to rise a few centimeters off the bottom under twilight conditions, the chances of capturing round whitefish larvae should be improved by night sampling. For this reason, night sampling has been conducted at most field sites since 1987.

Preliminary trials conducted with a stationary sled oriented into flume currents (created by draining the flume or operating a recirculating pump) resulted in substantial catches. Thus, it appears that a stationary net placed on the lake bottom (oriented into the longshore currents) may be successful in catching round whitefish larvae.



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To: Dr. D. Mills
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1.0 INTRODUCTION

Studies to assess the effects from thermal discharges on spawning round whitefish are ongoing at Pickering, Darlington and the Bruce Nuclear Power Development. Attempts to sample round whitefish larvae with tow nets (surface, midwater, or near-bottom) have generally not been successful. Although some success has been obtained with a benthic sled, catches have been small and irregular (OHRD Reports 82-539-K, 83-531-K, 87-82-K, 87-181-K). Initial sampling with the sled was conducted in daylight, but most recent sampling has been done during twilight or dark periods. In order to improve the effectiveness of the benthic sled, a study of larval whitefish response to a scale model sled was done in the laboratory. This study was conducted at the request of the Environmental Studies & Assessments Department.

Previous laboratory studies have indicated that round whitefish larvae are closely associated with the bottom after hatching (OHRD Report 83-57-K). Hence the benthic sled, which samples the water column just above the lake bottom, would appear to be the obvious choice for sampling these larvae. It was not clear whether the low catches observed were simply a reflection of the scarcity of round whitefish larvae or whether the sled was an inefficient collection device. It was speculated that the relatively large round whitefish larvae (11 to 12 mm long at hatch) might be capable of taking rapid avoidance action as the sled approached. Therefore, a video monitoring system was included in the laboratory apparatus, to allow monitoring of larval behavior as the sled approached and passed over the larvae. In addition, tests were conducted at various towing speeds, with coarse and fine cobble substrates, and with daylight and twilight illumination levels.

2.0 MATERIALS AND METHODS

2.1 Test Apparatus

The benthic sled used in the laboratory (Figure 1) was a 1/3 scale replica of the units used for field sampling. It consisted of a steel frame with runners, towing bridle and two conical collection nets with removable sample collection buckets. The nets and the screened openings on the sample buckets were constructed from 363 micron Nitex mesh. The sled was 140 cm long, 38 cm wide, 13 cm high and weighed about 7 kg. The openings of the collection nets were 16 cm wide x 9 cm high.

The sled was towed by a rope attached to the bridle shown in Figure 1. Tests were conducted in a flume constructed of steel framed acrylic plastic. The flume was 15 m in length, 1.2 m in width and 1.2 m in depth. Thus, the sled sampled 26.7% of the flume width. The bottom of the flume was smooth concrete. For the purposes of the present tests, a section of the flume bottom (about 3 m long) was completely covered with a cobble substrate. Either fine cobble (2-5 cm) or coarse cobble (5-15 cm) material was used. Removable fine mesh screens contained larval whitefish in this area until moments before a test. Tests were conducted by towing the sled the length of the flume, passing over the cobble area containing the larvae.

Larval response to the sled was monitored by a low-light video camera (and tape recorder) located opposite the cobble covered test area. Larvae were clearly visible in this lateral view, and any attempts to escape from the approaching sled could be observed. A curtain wall surrounding the flume and controlled overhead lighting allowed testing under realistic light levels. "Daylight" tests were conducted at an illumination level of about 10 lux, a reasonable approximation of daylight illumination at 7-10 m depth in Lake Ontario. It was not possible to obtain complete darkness in the flume due to lighting requirements in other parts of the building. However under the "twilight" conditions obtained, most larvae were observed to rise a few cm off the bottom, and some were well up in the water column (the flume was filled to about 80 cm). Under the extremely low light levels of the twilight tests (estimated to approximate 10^{-3} lux), larvae could be monitored with the low-light TV camera, but were very difficult to see with the unaided eye.

2.2 Experimental Procedures

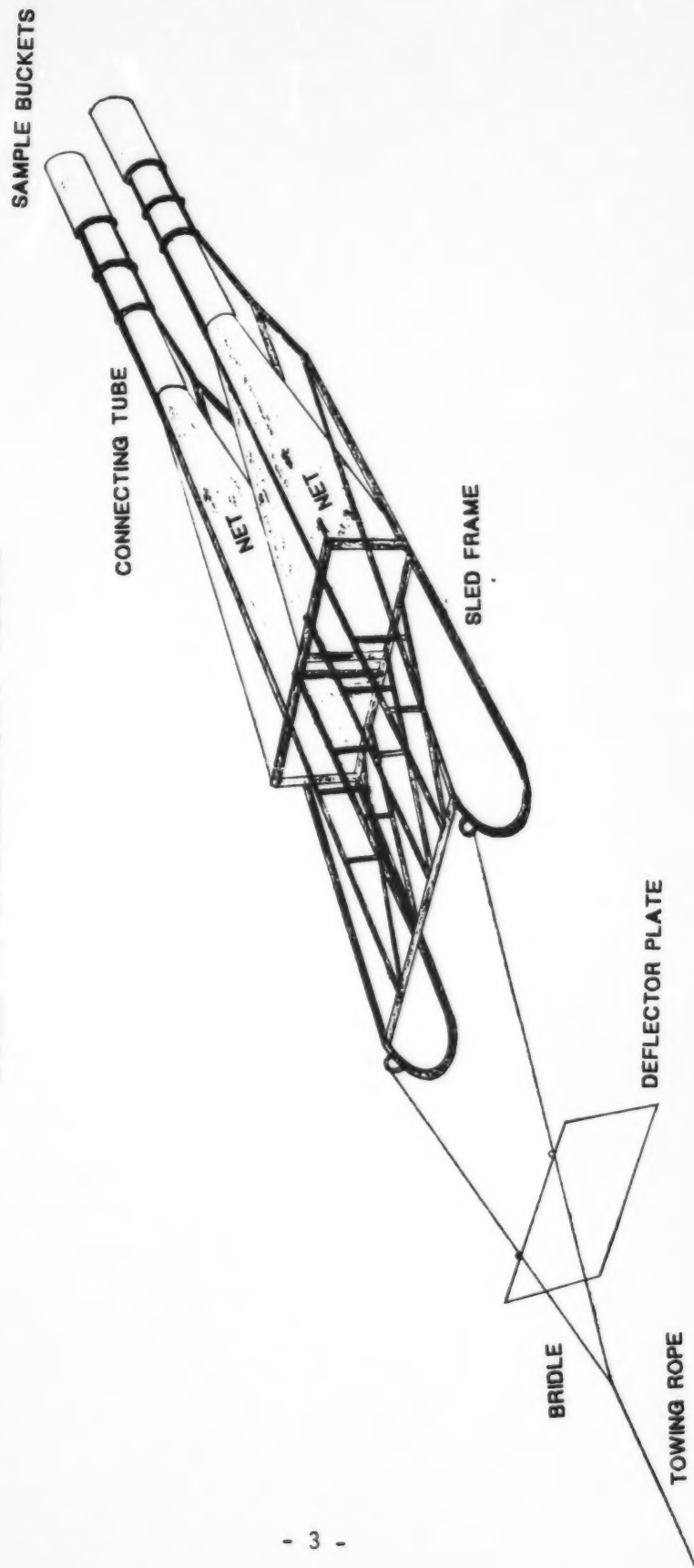
2.2.1 Test Fish

Adult round whitefish were collected from Lake Ontario near the Pickering and Darlington sites in December, 1984. Eggs were fertilized and incubated in the laboratory at Lake Ontario ambient temperatures. Hatch would normally occur over the mid-late April period.

Initial tests indicated that post-test removal of fry from the flume was extremely difficult. Complete recovery between tests was imperative, as any larvae from previous tests remaining on the cement flume bottom (upstream or downstream of the cobble test area) were quite vulnerable to capture and would bias subsequent test results. The only practical method of removal (complete dewatering and flushing of the flume between tests) made it difficult to conduct more than one test per day. This resulted in extension of the planned test period.

In order to prolong the hatching period and maintain newly hatched larvae as long as possible, temperatures in some incubators were not allowed to follow the normal spring temperature rise, and were maintained at 2 to 3°C. This allowed freshly hatched larvae to be available from early May until early July. In total, 23 tests were completed (Appendix 1) before the supply of healthy larvae was exhausted. Proposed experiments with larger, post-yolk-sac fry were not done, as

FIGURE 1
DETAILS OF BENTHIC SLED MODEL
USED IN LABORATORY TESTS



labour difficulties during May 1985 made it impractical to collect the live zooplankton required to feed the round whitefish fry.

2.2.2 Test Procedures

Prior to the beginning of a test, the benthic sled was positioned at the far end of the flume and the tow rope was placed along the bottom. Then, 400 larvae were added to the central portion of the flume, where they were contained by removable fine mesh screens. The larvae were allowed at least 1 hour to become accustomed to the apparatus. Light levels were set to the desired test conditions (daylight or twilight) shortly after the fish were introduced to the flume. The TV monitoring and recording system located opposite the larval enclosure was turned on and adjusted.

At the start of the test, the screens were raised, and within about 30 seconds, the sled tow began. The sled was towed by hand for the length of the flume by an operator standing in chest waders near the end wall of the flume. While better speed control might have been attainable using a mechanical towing system, the small number of tests involved and limited time made development of an automated system impractical. After a little practice, it was concluded that an adequate job was done manually. Timing of a number of practice runs suggested that speeds were within about $\pm 10\%$ of desired velocities over the 0.5 to 1.0 m/s range. It is unlikely that velocity control of sled tows in the field would be more precise than in these laboratory tests. Speeds above 1.0 m/s were difficult to maintain, and the sled bounced badly after striking the cobble substrate. Hence, tests were not conducted at speeds above 1.0 m/s. As the sled approached the end of the flume, it was smoothly raised to the surface to prevent escape of captured larvae. The nets were then thoroughly washed down to ensure that all captured larvae were in the sample buckets. Captured larvae were then removed and enumerated. The flume was dewatered and rinsed to remove all remaining larvae. Dechlorinated tap water at ambient temperature was used to fill the flume. During the test period, flume temperatures ranged from 7.5 to 11.0°C.

2.2.3 Experimental Design

Initial tests indicated that the model sled was quite effective at capturing larvae on a smooth surface. Approximately 20% capture was obtained with a bare concrete flume bottom during initial trials to establish test procedures. Assuming that most larvae were within a few centimeters of the bottom (this was clearly the case under "daylight" conditions), the theoretical maximum potential capture can be calculated by comparing the width of the two net openings with the flume width. This amounts to 26.7% (32 cm/120 cm). Thus, the gear efficiency for capture in the bare concrete flume approximates 75% (20/26.7) of the theoretical maximum efficiency. These initial results plus the abundance of cobble substrates encountered in the field resulted in deletion of the proposed sand substrate tests. Instead, two grades of cobble substrate (2-5 cm; 5-15 cm material) were tested, as it was believed that these would more realistically represent field conditions.

Review of the videotapes obtained as tests progressed suggested that larvae might be more vulnerable to capture in dim light, as they more frequently tended to rise a few centimeters off bottom under these conditions. Hence, roughly equal emphasis was given to daylight and twilight tests.

Video tape records indicated that larvae showed little fright response or avoidance as the sled approached. This, combined with technical difficulties of operation at high speed (the sled tended to bounce over the cobble bottom and reliable speeds were difficult to obtain) resulted in

towing velocities being restricted to the 0.5 to 1.0 m/s range, with most tests being conducted at the lower speed.

In an attempt to improve capture success, two modifications not considered in the original proposal were tested. The first was the addition of a deflector plate towed in front of the sled in an attempt to raise larvae off the bottom and make them more susceptible to capture by the nets (Figure 1). The videotape records suggested that larvae might be lifted off the bottom by the eddy currents behind the deflector. The second modification was the use of the sled as a passive (stationary) collector, introducing currents (to simulate lake currents) with the recirculation pump attached to the flume, or by draining the flume from one end.

3.0 RESULTS AND DISCUSSION

3.1 Effects of Substrate and Light on Catch

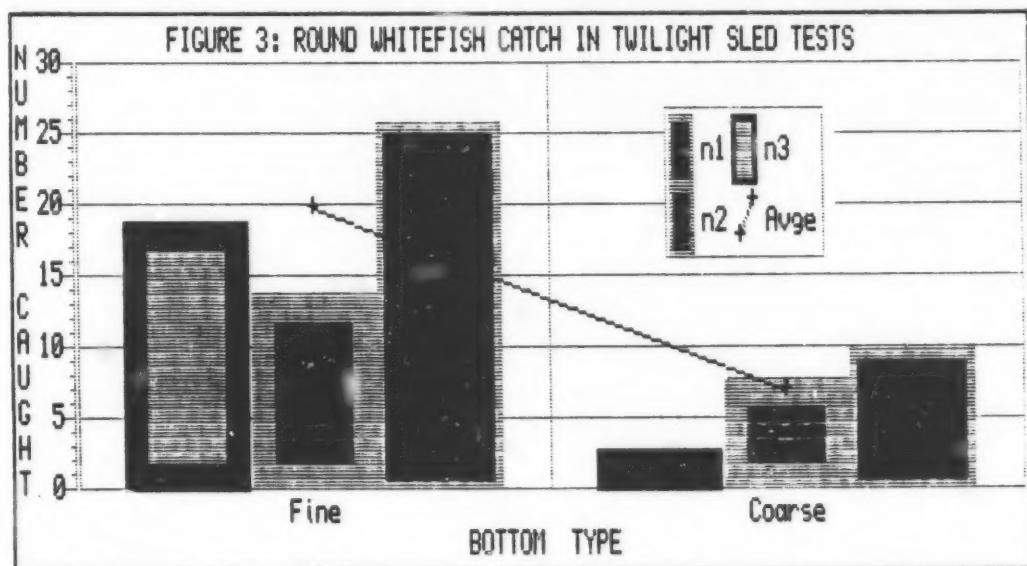
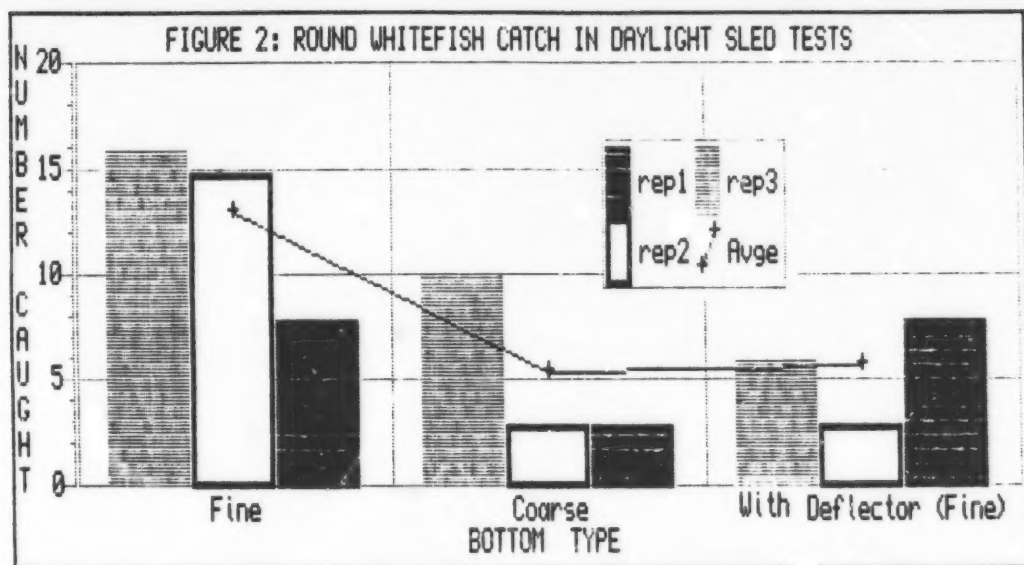
Data collected during the sled tests are listed in Appendix 1. Results for the daylight tests conducted at 0.5 m/s velocity are plotted in Figure 2. Three replicate tests were run with fine cobble substrates (2 - 5 cm material) and coarse cobble substrates (5 - 15 cm material). The average number of round whitefish larvae caught (400 larvae were used per test) declined from 13/tow with the fine cobble to 5.3/tow with the coarse cobble substrate. Average catches in twilight tests were also lower in coarse cobble substrates, declining from 19.7/tow to 7/tow (Figure 3). The average twilight catch (both substrate types) was 13.3 larvae/tow, about 45% higher than the average daylight catch of 9.2/tow. A two-way Analysis of Variance was conducted on the substrate x light data shown in Figures 2 and 3. Change from fine to coarse substrates resulted in a highly significant capture reduction (Figure 4, Appendix 2A). Although average catches were higher in the twilight tests than in daylight tests, the difference was not statistically significant.

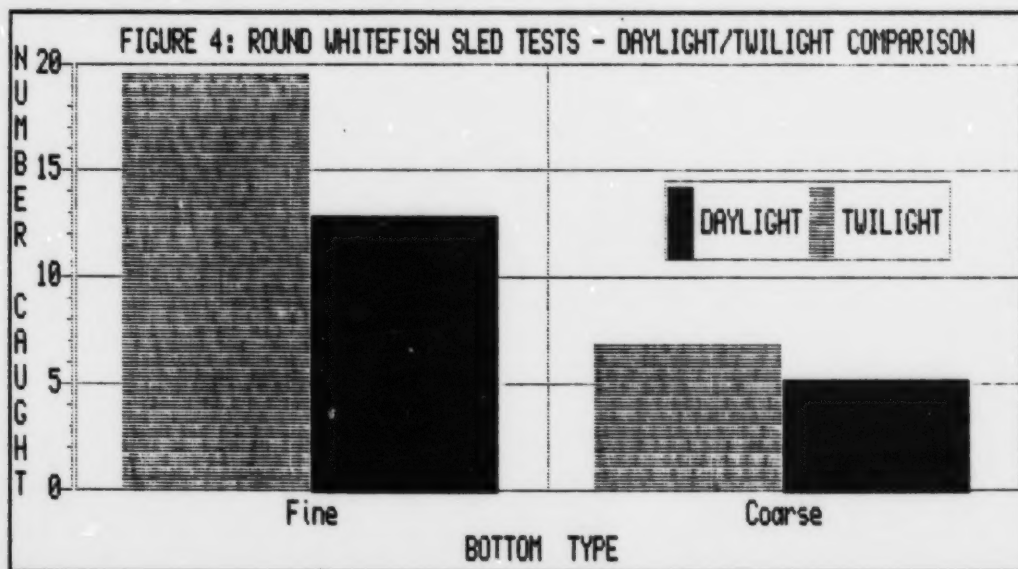
Both arithmetic and log-transformed catch values were analysed (Appendix 2A). Results of both analyses were similar.

3.2 Effects of a Deflector Plate

Three tests were conducted with the deflector plate mounted in front of the sled (Figure 1). These tests were run in daylight, with a fine cobble bottom, at a speed of 0.5 m/s. The average catch (5.7 fish/tow) was less than half the value obtained without the deflector in place (Figure 2). The difference approached, but did not attain statistical significance (Appendix 2B). Both arithmetic and log-transformed catches gave similar results (Appendix 2B).

The poor performance with the deflector plate was unexpected. Review of the videotapes during the preceding tests had suggested that substantial numbers of larvae were lifted off the substrate and tumbled in midwater by eddies and vortices in the wake of the sled. Therefore, it was reasoned that if vortices could be created upstream of the sled nets, larvae might be lifted off the bottom and be made more vulnerable to capture. Videotapes made without fish suggested (from disturbance of fine sediments in the substrate as the deflector passed by) that appropriate current patterns were created by the deflector, and during tests with fish, several larvae were seen to be tumbled in front of the collecting nets as the sled passed by. Thus, low catches with the deflector were unexpected. It is suggested that a similar device has the potential to improve catches in a full-sized sled. However, considerable development would be required to determine the optimum size, shape, attachment point and towing speed for a deflector. In the present study, sufficient numbers of larval fish (and time) were not available to improve the deflector. As tested in the present study, the deflector must be considered an impediment rather than a benefit.





3.3 Effects of Sled Towing Velocity

Only a few tests were conducted at higher velocities (>0.5 m/s) before the supply of round whitefish larvae was exhausted (Appendix 1). Tests made in daylight (fine cobble) with and without the deflector are compared with appropriate low-speed (0.5 m/s) tests in Figure 5. While these data are very limited, they suggest that little improvement would be gained by increasing sled speeds above 0.5 m/s, and catches may actually decline at higher speeds. Observations on sled behavior support this belief, as at higher speeds, the sled tended to bounce (as much as 10 cm) above the cobble surface. Given the habit of the larvae to remain very close to the substrate, any tendency for the sled to bounce off the bottom would deleteriously affect catch. Analysis of the results (both arithmetic and log-transformed values; Appendix 2C) indicates that catch did not vary significantly with towing speed.

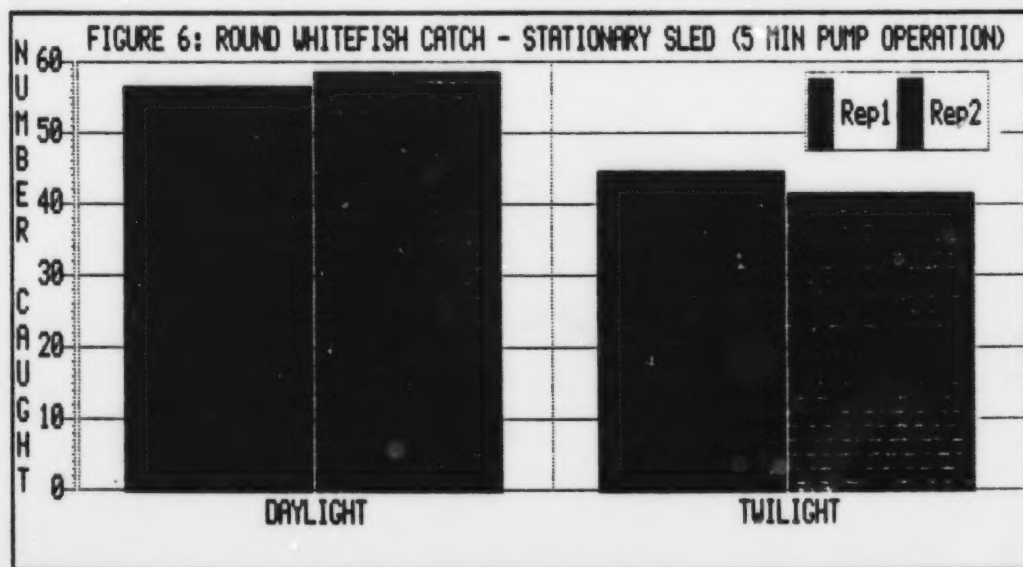
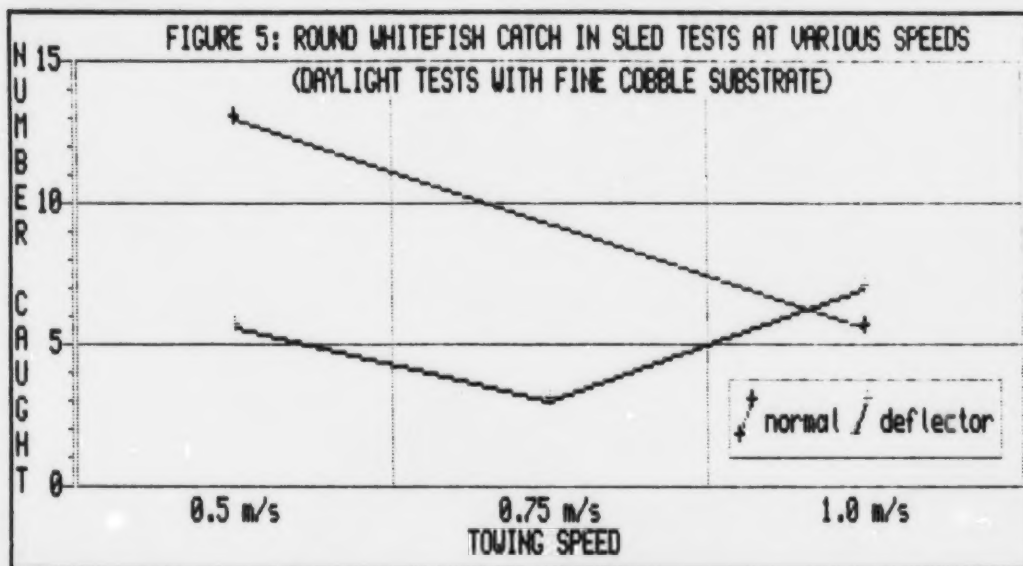
Field towing speeds have approximated 1.0 m/s, which would likely result in some bouncing of the full-scale sled over rough cobble substrates. It should be noted that the field sled is much larger and heavier than the lab scale model, and is therefore less likely to bounce at a given speed. However, our field experience at the Darlington site indicates that the sled does bounce over the lake bottom, and often "hangs up" temporarily when striking large boulders. Damage to the sled has occasionally resulted from striking boulders. Although the author has suggested to field crews that towing speeds be reduced to near 0.5 m/s, reduced speeds have made it very difficult to maintain steerage way, and the sled has a tendency to "dig in" to sandy substrates. The result is a net and collecting bucket so filled with sand that recovery of any larval fish would be impossible. Consequently, the towing speed of approximately 1.0 m/s has been retained for field operations. Present limited results give no indication that it should be increased.

3.4 Tests With a Stationary Sled

In the course of conducting the above tests, larval behavior during the post-test period (when the flume was being drained to remove larvae not caught in the previous test) was observed and occasionally recorded on videotape. It was noted that as the tank drained, some larvae swam downstream with the current, while others oriented into the current and maintained position for varying periods of time before being carried downstream by the current. Most larvae appeared to be carried downstream by currents of less than 10 cm/s (as roughly estimated by timing movement of detritus particles across the camera's field of view). As these velocities were comparable to (or less than) average lake currents, it was reasoned that a stationary net oriented into the current might be successful in catching round whitefish larvae.

The first test consisted of placing the sled at the "downstream" end of the cobble substrate (after completion of a regular towing test) and then draining the tank with the sled facing into the current. When this "stationary sled" test began, several minutes had elapsed since the towing test and the approximately 400 larvae had dispersed throughout the flume. Hence, it is assumed that approximately half of the larvae were already downstream of the sled and were not vulnerable to capture when the flume was drained. The catch on this "single pass" test totaled 5 larvae in the sled nets, plus an additional 4 taken in a small Wisconsin net located about a meter downstream of the sled nets (Appendix 1). These results clearly suggested that larval round whitefish could be caught by stationary nets when current velocities were quite low.

Four tests were also conducted using the large recirculation pump to create a current in the flume. These tests were also conducted using larvae remaining in the flume after normal tows. For these tests, the sled was placed on the cobble substrate, oriented into the current. A large gate valve adjacent to the pump was partially closed to restrict flow as much as possible. Under



these conditions, flow past the sled (estimated by timing detritus particles about 10 cm off bottom) was about 20 cm/s. In each test, the pump was operated for 5 minutes. Calculations indicate that during this period, larvae would be carried past the nets four times. Catches were quite consistent, averaging 58 larvae/test in daylight and 43.5 larvae/test in twilight (Figure 6, Appendix 1).

Most of the larvae captured in these tests appeared to be in good condition. However, it is quite possible that passage through the pump caused sufficient disorientation to render them unable to avoid the sled nets. One possible way to assess their condition is to determine if they were maintaining their preference for the flume bottom (as opposed to being randomly mixed throughout the water column). Comparison of cross-sectional areas indicates that the nets sampled 3% of the flume x-section. Assuming that the larvae passed the net 4 times during the test, the theoretical maximum catch (for randomly distributed larvae) was calculated as 45.8/test (calculations made allowance for the progressive reduction in the "population" on each pass by the net). The average catch in the twilight tests was 95% of this value, but the daylight catch was 127% of the calculated maximum. Thus, the daylight results suggest that the larval whitefish were concentrated towards the bottom.

While these tests must be viewed as preliminary trials, results suggest that round whitefish larvae can be captured by stationary nets fixed to the lake bottom and oriented into the current. Lake currents consistently run at or above the velocities estimated during the period when the flume was drained (<10 cm/s). High catches during the trials with the recirculating pump may in part be due to adverse effects of pump passage, although catch in the daylight tests suggested that the fish were at least orienting towards the bottom.

3.5 General Discussion and Summary

Observations of round whitefish larvae made during both daylight and twilight tests indicated that most larvae were within 10 cm of the substrate, and should be vulnerable to capture during the towing tests. Therefore, sled capture efficiency can be computed on the basis of the relative widths of the flume and the sled nets. Such computations indicate that the highest average catch (19.7 fish/tow) during the twilight tests on fine cobble was equivalent to a capture efficiency of 18.4% of the theoretical maximum catch. The capture efficiency was 12.2% in daylight on fine cobble. Efficiencies on coarse cobble substrate were 5.0 and 6.6% respectively for daylight and twilight tests. Computations based on the likely minimum number of spawning adults, and hence the estimated larval density in the Thickson Point area east of Pickering suggested that field sled capture efficiencies during 1984 and 1985 did not exceed 3.1% and 3.5%, respectively (OHRD Report 87-181-K). In view of these results, it seems reasonable to conclude that the benthic sled does not capture round whitefish larvae very efficiently, suggesting that substantial gains in efficiency should be possible.

The substrate composition is one of the major factors affecting capture efficiency. Preliminary daylight tests with a smooth flume bottom suggested a capture efficiency near 75%. On fine cobble, daylight efficiency declined to 12.2%. With the addition of coarse (5 - 15 cm) cobble, efficiency was depressed to 5%. The decrease in sled efficiency appears to be the result of two factors. Although the larvae seldom made obvious movements to avoid capture, the increased irregularity of the substrate provided numerous small depressions which could not be sampled by the sled nets. Thus, larvae within a few centimeters of the bottom could not be readily captured. Also, the irregular surface caused the sled to bounce several centimeters off the bottom, further reducing its effectiveness.

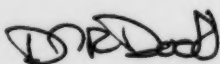
Since much of the substrate in the vicinity of the BNPD, Pickering and Darlington sites is

composed of relatively large, irregular material (cobble or boulder) it is not surprising that larval catches in the field are low. It is noteworthy that one of the largest single-tow catches of round whitefish larvae (12 fish) was made over an area of smooth sand substrate in Inverhuron Bay near Bruce "B" (Balesic, pers. comm.). Unfortunately, distinct areas of smooth substrate are difficult to find in the vicinity of Pickering and Darlington. The glacial till substrates in the nearshore zone (5-12 m) are extremely heterogeneous. In this situation, perhaps the best that can be done is to slightly reduce towing speed to minimize the bouncing of the sled. As previously mentioned, substantial reductions in sled speed may not be desirable due to large amounts of sand collected if the sled hits a sand patch. However, it must be emphasized to the field crews that the sled is effective only if it is in contact with the bottom as much as possible. Therefore, tows should be made at the slowest reasonable speed.

Although the difference between daylight and twilight catches was not statistically significant in the present study, this is probably due to the small number of replicates (3) possible in the present study. As the average twilight catch was some 45% higher than the daylight catch, and the larvae were seen to rise a few centimeters off bottom under the twilight conditions, it is believed that the chances of capturing round whitefish larvae will be improved by night sampling. For this reason, night sampling has been conducted at most sites since 1987.

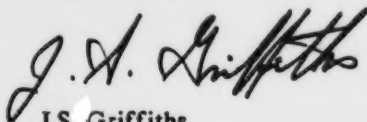
The lack of attempts to escape as the sled approached and the presence of many larvae tumbling in mid-water in the wake of the sled suggests that a properly designed deflector should have the potential to lift larvae off bottom and make them vulnerable to the sled nets. As used in the present tests, the deflector plate appeared to be more of an impediment than a benefit. It is possible that to be effective, the deflector should have been placed further ahead of the sled (possibly up to 2 meters). Greatest abundance of larvae in the wake of the sled occurred several seconds after the sled passed. In 1986, about 8 small deflectors were added to the front crossbar of field sleds. These consisted of rectangular pieces of steel plate (about 20 cm high x 10 cm wide) which hung from chains attached to the crossbar. Their action was probably more similar to the steel chain "ticklers" previously used on these sleds than the deflector used in the lab studies. Due to the tendency of these plates to tangle, they were removed from the sleds used in Lake Ontario in 1987. Design of an effective deflector is clearly not a simple task. The size, shape, method of attachment, location and towing speed are all important variables determining the effectiveness of a deflector. Unfortunately, the low number of larvae captured in the field make it very difficult to obtain the data necessary to develop an effective deflector.

Approved by:



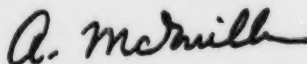
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Appendix 1

Round Whitefish Catch in Sled Tows

DATE	LIGHT	SPEED (M/S)	SUBSTRATE	TEMP (°C)	CATCH (400/TEST)
17/05/85	DAY	0.5	FINE	9.4	8
07/06/85	DAY	0.5	FINE	9.5	15
17/06/85	DAY	0.5	FINE	9.5	16
18/06/85	TWILIGHT	0.5	FINE	10.0	26
20/06/85	TWILIGHT	0.5	FINE	8.0	14
25/06/85	TWILIGHT	0.5	FINE	8.5	19
27/06/85	DAY	0.5	COARSE	8.9	3
11/07/85	DAY	0.5	COARSE	8.5	3
11/07/85	DAY	0.5	COARSE	8.5	10
26/06/85	TWILIGHT	0.5	COARSE	9.5	10
28/06/85	TWILIGHT	0.5	COARSE	9.0	8
12/07/85	TWILIGHT	0.5	COARSE	10.0	3
29/05/85	DAY	0.5 (DEF.)	FINE	10.5	8
05/06/85	DAY	0.5 (DEF.)	FINE	9.0	3
06/06/85	DAY	0.5 (DEF.)	FINE	8.0	6
06/06/85	DAY	0.75 (DEF.)	FINE	7.5	3
31/05/85	DAY	1.00 (DEF.)	FINE	11.0	7
24/05/85	DAY	1.00	FINE	9.5	6
19/06/85	TWIL	TANK DRAIN	FINE	9.0	5 +4(WISC.)
20/06/85	DAY	PUMP (5 MIN)	FINE	8.0	59
27/06/85	DAY	PUMP (5 MIN)	COARSE	8.9	57
25/06/85	TWIL	PUMP (5 MIN)	FINE	8.5	42
26/06/85	TWIL	PUMP (5 MIN)	COARSE	9.5	45

Appendix 2A

Analysis of Sled Catch Data

Effects of Substrate x Light

ANALYSIS OF VARIANCE (ARITHMETIC)

SOURCE OF VAR	SUM SQUARES	df	MEAN SQUARE	F-RATIO
SUBSTRATE (A)	310.0833	1	310.0833	14.6496 **
LIGHT (B)	52.0833	1	52.0833	2.4606 NS
AxB	18.7500	1	18.7500	0.8858 NS
ERROR	169.3333	8	21.1667	
TOTAL	550.2500	11		

ANALYSIS OF VARIANCE (LOG 10 TRANSFORM OF CATCH)

SOURCE OF VAR	SUM SQUARES	df	MEAN SQUARE	F-RATIO
SUBSTRATE (A)	0.5018792	1	0.5018792	12.70781 **
LIGHT (B)	6.334443E-2	1	6.334443E-2	1.60391 NS
AxB	2.337791E-3	1	2.337791E-3	0.05919 NS
ERROR	0.31595	8	3.949375E-2	
TOTAL	0.8835114	11		

* $F_{0.05(1,8)} = 5.318$

** $F_{0.01(1,8)} = 11.25$

Appendix 2B

Analysis of Sled Catch Data

Normal Sled vs Sled with Deflector

ANALYSIS OF VARIANCE (ARITHMETIC)

SOURCE OF VAR	SUM SQUARES	df	MEAN SQUARE	F-RATIO
TREATMENTS	80.66667	1	80.66667	6.368 NS
WITHIN	50.66667	4	12.66667	
TOTAL	131.3333	5		

ANALYSIS OF VARIANCE (LOG 10 TRANSFORM OF CATCH)

SOURCE OF VAR	SUM SQUARES	df	MEAN SQUARE	F-RATIO
TREATMENTS	0.2109145	1	0.2109145	5.579596 NS
WITHIN	0.1512042	4	3.780104E-2	
TOTAL	0.3621187	5		

* $F_{0.05(1,4)} = 7.71$

Appendix 2C
Analysis of Sled Catch Data
Effects of Sled Velocity

ANALYSIS OF VARIANCE (ARITHMETIC)

SOURCE OF VAR	SUM SQUARES	df	MEAN SQUARE	F-RATIO
TREATMENTS	40.16667	2	20.08333	0.914 NS
WITHIN	131.83333	6	21.97222	
TOTAL	172.00000	8		

ANALYSIS OF VARIANCE (LOG 10 TRANSFORM OF CATCH)

SOURCE OF VAR	SUM SQUARES	df	MEAN SQUARE	F-RATIO
TREATMENTS	2.342173E-2	2	1.171086E-2	0.1928 NS
WITHIN	0.3643596	6	6.07266E-2	
TOTAL	0.3877813	8		

* $F_{0.05(2,6)} = 5.14$